HUMAN BiOLOGY AND PUBLiC HEALTH
JOURNAL OF THE AUXOLOGICAL SOCIETY

ISSN 2748-9957 | Vol. 3 2022 | pp. 1–16

From the fattest to the tallest? – The association patterns between childhood obesity and body height during adolescence

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Citation:

Kirchengast, S./Hagmann , D. (2022). From the fattest to the tallest?, Human Biology and Public Health 3.
https://doi.org/10.52905/hbph2022.3.41.

Received: 2022-07-22
Accepted: 2022-11-02
Published: 2023-03-10

Conflicts of interest:

The authors declared no conflicts of interest.

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Keywords:

childhood obesity, growth patterns, developmental tempo, body height, adolescence

Abstract

Background Growth and finally body height are influenced by various intrinsic and extrinsic factors. During the last decades the well documented secular trend of increase in body height slowed down. Overweight and obesity rates increased worldwide from childhood onwards. An association between rising obesity rates and the slowdown of the secular trend in body height might be assumed.

Aims This study focuses on patterns of associations between childhood weight status, socioenvironmental factors, and adolescent body height. It is hypothesized that higher weight during childhood enhances developmental tempo and linear growth, and results in higher body height during adolescence.

Sample and methods In a longitudinal study, the body height, body weight, and Body mass index (BMI) of 1506 randomly selected Viennese children were documented at the age of six, ten, and fifteen years. Weight status according to sex and age and age-specific BMI percentiles were determined. The association between weight status and body height was analyzed. A history of migration and the socioenvironmental background, based on specific characteristics of the residential area, have been included in the analysis.

Results A marked positive association between weight status during childhood, male sex, socioenvironmental factor, the background of migration, and body height at the age of six and ten years could be documented. At the age of fifteen years, however, only male sex and BMI at age ten years were significantly positively associated with height.

Conclusion High weight or obesity during childhood enhances growth during childhood, but no significant associations between weight status and height were observable during adolescence.

Take-home message for students Body weight and BMI are significantly associated with body height during childhood and prepubertal age. An enhanced developmental tempo caused by overnutrition can be assumed as a trigger factor of linear growth during childhood, resulting in higher body height during the prepubertal phase. However, during adolescence, no significant associations between Body mass index and height are observed.

Introduction

Body height and linear growth in general have been interpreted as valid indicators for the state of health and living conditions of children and adolescents since the 19th century (Komlos 1993; Steckel 1995). Besides poor living conditions, repeated infectious diseases, parasite infestation, psychosocial deprivation, first of all, malnutrition, and long-term starvation have been discussed as special risk factors for growth restriction, growth retardation, and finally shortness. For a long time, a poor diet, characterized by a quantitative lack of food as well as a lack of essential components such as vitamins, trace elements, and proteins and also fat, was interpreted to be a special inhibitor of an undisturbed growth process. The affected children were too short for their age, a phenomenon which is commonly called stunting. According to the World Health Organization (WHO), children are defined as stunted if their height for age is more than two standard deviations below the WHO Child Growth Standards median (WHO 2021). Consequently, the association patterns between diet or nutritional status and body height were mainly focused on from the viewpoint of malnutrition resulting in lower body height (Lifshitz 2009), and an adequate diet was stylized as the key to an undisturbed growth process and increasing body height. Currently, however, the appropriateness of stunting as an indicator of malnutrition in early childhood has been falsified (Scheffler et al. 2020; Scheffler and Hermanussen 2022) and although severe long-term malnutrition in early childhood may result in lower body height, the effectiveness of food interventions to stimulate somatic growth is now viewed critically (Hermanussen et al. 2018). Somatic growth and development are currently seen as multidimensional processes, that are not only influenced by nutrition and biological factors, but mainly by socio-cultural and emotional factors as discussed by Bogin (Bogin 2021b) in the SEPE (Social-Economic-Political-Emotional) concept. Nevertheless, the importance of improved nutrition is, besides generally improved living conditions, still used as an explanatory model for the undeniable trend of increasing heights in Europe during the last 180 years (Eveleth and Tanner 1990; Hauspie et al. 1997; Hauspie et al. 1996; Malina 1990; Malina 2004; van Wieringen 1986; Cole et al. 2000; Cole 2003; Padez 2007; Alter et al. 2004). In the last 50 years, living conditions, especially in industrialized countries, have further improved significantly. Under these favorable conditions, it might be assumed that the body heights continue to increase. But this is not true. The increase in mean body height has been slowing down in several European countries but also in the United States during the last 25 years (Roberts 1994; Komlos and Baur 2004). This is a rather paradoxical situation, because despite improved nutrition and generally better life circumstances and medical services, the secular trend slows down. Maybe the improved living conditions generate new problems, such as hyperalimentation and obesity, which may counteract a further increase in body height. Childhood overweight and obesity rates have increased over the last fifty years, even in middle- and low-income countries (Kimm and Obarzanek 2002; Dehghan et al. 2005; Kosti and Panagiotakos 2006; Lasserre et al. 2007; Kumanyika 2008). According to the WHO, more than 340 million children and adolescents aged 5 to 19 years correspond to the definitions of overweight or obesity in 2016. This tendency is really a dramatic one because as with obesity in adults, childhood obesity is acknowledged to be an important risk factor for metabolic and cardiovascular diseases, but also triggers the risk for psychic and emotional morbidity during childhood as well as during later life (Geiss et al. 2001; Latner and Stunkard 2003; McGee 2005; Lob-Corzilius 2007).

Childhood obesity has also an impact on somatic growth. Among adults, the associations between body height and obesity are weak, although an association between shortness and an increased risk for obesity as well as metabolic and cardiovascular diseases have been reported (Hermanussen et al. 2005; Bosy-Westphal et al. 2009). In childhood, however, numerous studies have shown a positive association between height and obesity (Bruch 1939; Papadimitriou et al. 2006; Stovitz et al. 2011; Freedman et al. 2002). There is a complex interplay between weight status, body fat, energy balance, and growth as well as pubertal development (Shalitin and Gat-Yablonski 2022). Obese children are taller than their non-obese age-matched counterparts, they experience accelerated skeletal and pubertal maturation (Li et al. 2017). This is due to the fact, that growth is a matter of size but also of tempo (Hermanussen 2010; Mumm et al. 2014). Being overweight or obese during childhood enhances developmental tempo, pubertal maturation, and somatic growth, resulting in earlier sexual maturation and greater body heights at a lower age. Maturational tempo accounts for about 50 % of body height variation in boys and 40 % in girls during puberty (Molinari and Hermanussen 2005). In this way, a positive association between weight status and body height during childhood up to puberty can be assumed. Furthermore, some longitudinal studies have shown a positive association between higher body height in childhood and an increased risk of obesity in adulthood (Freedman et al. 2000; He and Karlberg 2001; Stovitz et al. 2010; Stovitz et al. 2011; Johnson et al. 2012; van Dommelen et al. 2014; Navti et al. 2015; Freedman et al. 2002). According to these results, childhood growth patterns differ between young adults who are obese, overweight, or normal weight.

In this study, , the association patterns between of childhood weight status and body height during adolescence among Viennese schoolchildren are examined on for the first time. . Since weight status during childhood as well as growth patterns are significantly associated with SEPE factors (Bogin 2021a; Bogin 2021b), socioeconomic characteristics of the children's residential area and the background of migration have been included in the analysis. Consequently, in the present study, the following hypothesis is tested: The BMI as an indicator of weight status is positively associated with body height during childhood, prepubertal phase, and adolescence, independent of sociocultural and socioenvironmental factors.

Sample and methods

Study design

This longitudinal study is only a small part of a huge project focusing on weight status among Viennese schoolchildren. The main focus of this project was the longitudinal analysis of the prevalence of overweight and obesity from childhood to adolescence in Vienna. In several studies, the complex association patterns between weight status and socioeconomic factors such as migrant status have been analyzed (Kirchengast and Schober 2006a; Kirchengast and Schober 2006b; Kirchengast and Schober 2008; Kirchengast and Schober 2009). In the present study, the association patterns between weight status and body height as an indicator of linear growth, were tested between the age of 6 and 15 years.

Data collection of the whole project took place in strong cooperation with the Viennese school medical authority, which randomly selected 45 public secondary schools (so-called Hauptschulen) of Vienna (two from each of the 23 Viennese political districts). All schools were invited to participate in the project. We were given access to the anonymized examination data of the school medical service. The anonymized data of all pupils who completed compulsory schooling in the participating schools at the age of 15 in 2005 were included in the study. In addition, it was a strict inclusion criterion that a complete data set was available for the medical examinations at the age of 6, 10, and 15 years. Although Austrian schoolchildren undergo a mandatory medical examination every year, only data from the examination at the age of 6, 10, and 15 were included in the study.

Data collection

Stature height and body weight of all school children were measured by specially trained staff of the medical school authority. Stature was measured with an anthropometer to the nearest millimeter. Weight was recorded with a scale precise to +/- 100g. The children and adolescents were measured without shoes and wearing only underwear. The first examination took place at the age of 6 years before the child starts school. The second examination took place four years later, when primary school is finished at the age of 10 years, and the third and last examination took place at the age of 15 years, shortly before the end of compulsory. The data files including all medical information as well as data on stature height and body weight are archived by the Viennese school medical officers. We were allowed to use the data of the Viennese school medical service. We decided to use only complete data sets and excluded from the analyses all children whose data sets were incomplete. Altogether, we gained access to the data sets of 1506 children who started school in 1994. The birth year of all these children was 1988. Finally, the data sets of 781 male and 725 female participants were included in the sample.

Sociodemographic parameters

All participants of this study belonged to the lower or medium social strata of Vienna. The main indicators for this sociodemographic classification were the attendance at the public so-called Hauptschule as well as socioeconomic parameters such as educational level and profession of the parents. Data concerning the educational level and profession of the parents, however, were only available from a few participants. Therefore, we included data concerning the social environment of the participant's residential area in Vienna using the official sources of the Statistical Department of the Viennese Government (Stadt Wien 2020). For a detailed description of the included parameters see Kirchengast and Hagmann (Kirchengast and Hagmann 2022). A social environment factor was computed based on the factor scores of a principal component analysis that included all socioeconomic and environmental factors of the residential areas. In addition, the background of migration of each participating child was obtained. A background of migration was defined as being born in a country other than Austria and migrating to Austria for permanent residence, or where at least one parent was born in a country other than Austria. Unfortunately, no information regarding age at menarche or male voice breaking was available.

Anthropometry

Body height and body weight were measured at the age of 6, 10, and 15 years. The BMI kg/m^2 is widely used as an indicator of the weight status of children and adults. In the present study, the percentiles of the BMI of Austrian children published by Mayer et al. (Mayer et al. 2015) were used. According to the recommendations of Kromeyer-Hauschild et al. (Kromeyer-Hauschild et al. 2001) and the European Childhood obesity group (Zwiauer and Wabitsch 1997), the 10th percentile was used as the cut-off for underweight, the 90th percentile was used as the cut-off for overweight and the 97th percentile as the cut-off for obesity for each sex separately. Normal weight was defined as the 10th to 90th percentile. Body height was classified as short (below the 10th percentile), medium height (10th to 90th percentile), tall (90–97th percentile), and extremely tall (above the 97th percentile) using the references for Austrian children provided by Gleiss et al. (Gleiss et al. 2013). The percentiles of body height were used for each sex and each age group separately.

Statistical analyses

Statistical analyses were carried out by means of the SPSS (program version 26.0). The results of the Kolmogoroff–Smirnov test indicated that a normal distribution of the anthropometric data could be assumed, therefore, parametric tests were applied. After computing descriptive statistics (mean, standard deviation, percentiles) group differences were tested with regard to their statistical significance using student t-tests, ANOVAs (Duncan analyses), and Chi-squares (crosstabs). Principal component analyses (PCA) using varimax rotation were carried out in order to obtain more information about the structure of social and environmental data and to compute the socioenvironmental factor. To test association patterns between body height, BMI, sex, the background of migration, and social environment multiple regression analyses were computed.

Table 1 Sex differences in body height, body weight and BMI of 6-, 10-, and 15-year-old children and adolescents of Vienna (t-tests).

	males n=781		females n=725		Sign.
	mean	sd	mean	sd	p-value
6 years					
Body height (cm)	121.8	8.0	120.5	6.4	**0.001**
Body weight (kg)	24.6	5.4	24.1	5.6	0.161
BMI (kg/m^2)	16.45	2.42	16.48	2.72	0.837
10 years					
Body height (cm)	141.8	7.4	141.7	7.8	0.862
Body weight (kg)	38.7	9.7	38.8	10.6	0.817
BMI (kg/m^2)	18.93	3.58	19.08	3.99	0.525
15 years					
Body height (cm)	167.4	8,2	161.7	6.7	**0.001**
Body weight (kg)	61.9	13.3	58.1	12.5	**0.001**
BMI (kg/m^2)	21.89	3.92	22.15	4.25	0.221

Results

Sample characteristics

781 boys (51.9 %) and 725 girls (48.1 %) participated in the present study. 375 boys (48 %) were of Austrian origin, while 406 boys (52 %) had a background of migration. Among female participants 317 girls (43.7 %) were of Austrian origin, 408 girls (56.3 %) had a background of migration.

Sex differences in body height and body weight

As presented in table 1, male participants were significantly taller than their female counterparts at the age of 6 and 15 years. At the age of 10 years, no significant sex difference in body height could be stated. Male and female participants did not differ significantly in body weight at the age of 6 and 10 years. At the age of 15, male participants were significantly heavier than their female counterparts. The BMI at the age of 6, 10, and 15 years, however, did not differ significantly between males and females (table 1).
No significant differences between male and female participants could be observed in the prevalence of underweight, normal weight, overweight, and obesity for the age of 6 years, 10 years, and 15 years (table 2). At the age of 6 years, about 20 % of the girls and boys were classified as overweight or obese. This was true of nearly 30 % of boys and girls at the age of 10 years. At the age of 15 years, more than 25 % of male and female participants correspond to the definition of overweight or obesity (table 2).
As demonstrated in table 2, at the age of 6 years more than 23 % of the boys and more than 17 % of the girls corresponded to the definition tall or very tall, while this was true for only 7 % of the boys and nearly 10 % of the girls at the age of 10 years. At the age of 15 years, only about 6 % of the boys and 8 % of the girls could be classified as tall or very tall. While only 10 % of girls and boys were short at the age of 6 years, this was true of nearly 20 % of the boys and 17 % of the girls at the age of 10 years. At the age of 15 years, 14.5 % of the male and 17.3 % of the female participants were classified as short.
Considering differences between participants of Austrian origin and participants with a background of migration, significant differences in body height were found for boys as well as girls at the age of 6 and 10 years. Children with a background of migration were significantly taller than children of Austrian origin. At the age of 15 participants with a background of migration were shorter than their Austrian counterparts. Among female participants, these differences were of statistical significance. Significant differences in body weight were found among boys and girls at the age of 6 years and among girls at the age of 10 years. Children with a background migration were heavier than their Austrian counterparts (table 3).

Body height and weight status

In the next step, the BMI of short, medium, tall, and extremely tall participants was compared. Table 4 demonstrates the mean and standard deviation of the BMI according to the body height categories. Boys who were classified as short, or of medium height at the age of 6 years had significantly lower BMIs at the age of 6, 10, and 15 years, than boys, who have been classified as tall or very tall at the age of 6 years. The same trend was found for the association between the body height category at the age of 10 years and BMI. The shorter the boys were at 10 years the lower the BMI was at the ages of 6, 10, and 15 years. The significantly highest BMIs were found among

Table 2 Percentage of body height categories according to reference percentiles provided by Gleiss et al. (Gleiss et al. 2013) and weight status according to Mayer et al. (Mayer et al. 2015) of 6-, 10-, and 15-year-old children and adolescents of Vienna.

		males (n=781)			females (n=725)		
		6yrs	10yrs	15yrs	6yrs	10yrs	15yrs
Body height							
< 10th perc	short	10.3 %	19.8 %	14.5 %	10.4 %	16.6 %	17.3 %
10 to 90th perc	medium	66.5 %	73.2 %	79.4 %	72.2 %	73.1 %	74.7 %
90 to 97th perc	tall	13.4 %	3.6 %	4.9 %	9.7 %	6.6 %	5.5 %
>97th perc	very tall	9.9 %	3.3 %	1.2 %	7.7 %	3.7 %	2.5 %
Weight status							
< 10th perc	underweight	8.3 %	7.4 %	4.4 %	7.3 %	6.6 %	3.7 %
10 to 90thperc	normal weight	72.5 %	63.8 %	71.7 %	71.5 %	63.8 %	68.7 %
90 to 97th perc	overweight	9.2 %	18.9 %	14.2 %	11.0 %	15.7 %	15.1 %
>97th perc	obese	10.1 %	9.9 %	9.7 %	10.2 %	13.9 %	12.5 %

Table 3 Body height, body weight and BMI according to sex and origin (student t-tests) of 6-, 10-, and 15-year-old children and adolescents of Vienna.

	males					females				
	Austrian		background of migration		Sign.	Austrian		background of migration		Sign
	mean	sd	mean	sd	*p*	mean	sd	mean	sd	*p*
6 years										
Body height (cm)	121.3	6.6	122.3	6.7	**0.038**	119.8	6.1	121.1	6.6	**0.008**
Body weight (kg)	24.2	5.3	25.0	5.5	**0.031**	23.3	4.8	24.9	6.2	**0.001**
BMI (kg/m^2)	16.31	2.37	16.61	2.49	0.070	16.15	2.50	16.79	2.88	**0.003**
10 years										
Body height (cm)	141.1	6.9	142.5	7.9	**0.018**	140.9	7.6	142.4	8.0	**0.016**
Body weight (kg)	37.8	9.4	39.1	9.7	0.074	37.5	9.5	39.7	11.2	**0.008**
BMI (kg/m^2)	18.83	3.58	19.06	3.59	0.232	18.75	3.79	19.38	4.14	**0.038**
15 years										
Body height (cm)	167.2	8.3	167.5	8.3	0.310	162.2	7.2	161.3	6.4	**0.043**
Body weight (kg).	61.3	13.6	61.7	12.8	0.348	57.9	12.6	57.9	12.1	0.451
BMI (kg/m^2)	21.83	4,14	21.95	3.70	0.346	21.96	4.32	22.31	4.19	0.140

boys who were extremely tall at the age of 10 years. At the age of 15 years, extremely tall males showed the highest BMI values at the age of 10 and 15 years, however only the association with the BMI at the age of 10 years was statistically significant.

Similar trends could be observed for the female participants (table 4). At the age of 6 and 10 years, shortness was significantly associated with the lowest BMI values, while the highest BMI values were found among tall and extremely tall girls. At the age of 15, the lowest BMI value was found among extremely tall girls.

In the last step, the associations between body height and weight status, sex, the

Table 4 Body height and weight status according to age and sex (Duncan analyses) of 6-, 10-, and 15-year-old children and adolescents of Vienna.

	male participants				
	mean (sd)	mean (sd)	mean (sd)	mean (sd)	
body height 6 years	short <10th perc	medium 10-90th perc	tall 90-97th perc	extremely tall > 97th perc.	*p*-value
BMI 6yrs	15.91 (1.63)	15.99 (2.06)	17.61 (2.73)	18.50 (3.25)	**0.001**
BMI 10yrs	18.48 (3.34)	18.35 (3.21)	20.74 (3.84)	21.09 (4.41)	**0.001**
BMI 15yrs	21.49 (3.87)	21.48 (3.67)	23.40 (4.23)	23.44 (4.47)	**0.001**
body height 10 years	short <10th perc	medium 10-90th perc	tall 90-97th perc	extremely tall > 97th perc.	
BMI 6yrs	15.71 (1.92)	16.57 (2.51)	16.73 (2.92)	17.93 (2.77)	**0.002**
BMI 10 yrs	17.25 (2.86)	19.02 (3.60)	19.83 (3.64)	20.79 (4.29)	**0.001**
BMI 15yrs	20.09 (3.76)	22.25 (3.89)	22.35 (3.12)	24.62 (4.43)	**0.001**
body height 15 years	short <10th perc	medium 10-90th perc	tall 90-97th perc	extremely tall > 97th perc	
BMI 6yrs	15.85 (2.09)	16.51 (2.43)	17.39 (3.41)	17.35 (2.45)	0.065
BMI 10yrs	17.17 (2.95)	19.12 (3.59)	19.95 (3.99)	20.38 (3.36)	**0.041**
BMI 15yrs	19.95 (3.08)	22.13 (3.09)	22.92 (4.29)	23.07 (3.47	0.584
	female participants				
body height 6 years	short <10th perc	medium 10–90th perc	tall 90–97th perc	extremely tall > 97th perc.	
BMI 6yrs	15.29 (1.94)	16.19 (2.28)	18.22 (3.34)	18.63 (4.04)	**0.001**
BMI 10yrs	16.97 (2.51)	18.94 (3.74)	21.21 (4.83)	20.93 (5.31)	**0.001**
BMI 15yrs	20.49 (3.22)	22.14 (4.08)	24.25 (4.08)	23.08 (4.09)	**0.009**
body height 10 years	short <10th perc	medium 10–90th perc	tall 90–97th perc	extremely tall > 97th perc.	
BMI 6yrs	15.33 (1.95)	16.55 (2.59)	18.12 (3.75)	17.98 (4.16)	**0.001**
BMI 10 yrs	17.71 (2.99)	19.21 (3.73)	21.02 (5.79)	21.68 (5.23)	**0.001**
BMI 15yrs	20.10 (2.78)	22.46 (4.14)	24.38 (4.88)	24.00 (4.91)	**0.001**
body height 15 yrs	short <10th perc	medium 10–90th perc	tall 90–97th perc	extremely tall > 97th perc.	
BMI 6yrs	15.95 (2.26)	16.62 (2.83)	16.07 (2.51)	16.90 (2.96)	0.084
BMI 10yrs	17.68 (3.21)	19.40 (4.14)	18.31 (3.01)	19.46 (4.18)	0.059
BMI 15yrs	21.61 (4.23)	22.28 (4.25)	22.31 (3.79)	21.49 (4.53)	0.541

background of migration, and the socioenvironmental factor were tested by means of multiple regression analyses. Body height at the age of 6 years was significantly positively associated with the BMI, the background of migration, the socioenvironmental factor, and the male sex. At the age of 10 years, body height showed significantly positive associations with the BMI at the age of 6 and 10 years, and the background of migration, while no significant associations with the socioenvironmental factor and sex were found. At the age of 15 years, male sex and the BMI at the age of 10 years were significantly associated with body height. The BMI at the age of 6 and 15 years, the background of migration and the socioenvironmental factor showed no significant association with body height (table 5).

Table 5 The impact of sex and BMI on body height at the age of 6-, 10-, and 15-year-old children and adolescents of Vienna (multiple regression analyses).

	R2	Reg Coeff	p-value	CI 95 %
Dependent variable: Body height at 6 years				
sex	0.349	-1.43	**<0.0001**	-2.07 – -0.59
BMI 6 years		0.82	**<0.0001**	0.68 – 0.97
Migration background		0.96	**0.013**	0.20 – 1.72
Social environment factor		0.43	**0.030**	0.40 – 0.81
Dependent variable: Body height at 10 years				
sex	0.351	-0.43	0.354	-1.32 – 0.43
BMI 6 years		0.31	**0.018**	0.05 – 0.57
BMI 10 years		0.469	**<0.001**	0.29 – 0.64
Migration background		1.19	**0.012**	0.27 – 2.12
Social environment factor		0.11	0.659	-0.37 – 0.58
Dependent variable: Body height at 15 years				
Sex	0.38	-5.63	**0.0001**	-6.28 – -4.67
BMI 6 years		0.19	0.176	-0.09 – 0.46
BMI 10 years		0.29	**0.012**	0.06 – 0.53
BMI 15 years		-0.03	0.720	-0.22 – 0.15
Migration background		0.12	0.918	-0.87 – 1.10
Social environment factor		0.37	0.147	-0.13 – 0.87

Discussion

The association patterns between weight status, particularly obesity and body height are discussed controversially. While some authors declared obesity and body height as unrelated during adulthood (Stovitz et al. 2011), others reported that shorter-than-average adults are at a higher risk of obesity and associated metabolic disorders (Bosy-Westphal et al. 2009). Komlos and Baur described the increase in obesity rates, but a stagnation or even a reduction of body height in the United States at the beginning of this millennium. They interpreted this shift from the tallest population in the World to one of the fattest as a result of increasing social inequality (Komlos and Baur 2004). Considering the situation during childhood and adolescence, some studies yielded a significantly positive association between obesity and body height during subadult phase (Kain et al. 2005; Buchan et al. 2007; Navti et al. 2015). Furthermore, an independent association between body height in childhood and adult BMI was reported (Freedman et al. 2002). The analysis of the association patterns between weight status and growth patterns, particularly body height, is of special interest because being overweight or obese is associated with increased morbidity and mortality risks and therefore important public health problems. The analysis of associations between linear growth patterns and weight status might allow the usage of growth patterns during childhood as a predictor for further weight status development and the risk of developing obesity.

In the present study, we hypothesized that the BMI as an indicator of weight status is positively associated with body height during childhood, prepubertal phase and adolescence, independent of sociocultural and socioenvironmental factors. There is no doubt that human growth is a complex process, which is physiologically regulated by endocrine factors, but the hormonal situation is influenced by psychosocial and environmental factors (Bogin 2021a; Bogin 2021b). The focus of the present study however is on the association between growth and weight status, which might be interpreted as an indicator of nutritional habits, in particular hyperalimentation resulting in overweight and obesity. Furthermore, it should be explicitly noted at this point that the target size is the body height at the age of 15 years, but at this age the linear growth process is not yet complete in both biological sexes. This is in contrast to some other studies, which analyzed the association patterns between the growth process and weight status, in particular on overweight and obesity rates in young adulthood (Stovitz et al. 2010; Stovitz et al. 2011; van Dommelen et al. 2014). In the present study, however, the age of 15 is defined as the final height, although, as mentioned above, the growth process is not completed at this age.

In the present study, the first thing that stands out is the high proportion of participants classified as short, i.e., a body height below the 10th percentile of the reference population (Gleiss et al. 2013) at the age of 10 and 15 years. On the one hand between 14.5 and 19.8 % of the participants (male and female) were short at the age of ten and fifteen years. On the other hand,, the amount of tall or extremely tall boys were more than 20 % at the age of 6 years. This was true for more than 17 % of the 6 years old girls. At the age of 10 and 15 years, less than 10 % of the male, as well as female participants, corresponded to the definition of tall or extremely tall, i.e., above the 10th percentile according to Gleiss et al. (Gleiss et al. 2013). These obvious differences to the Austrian reference population (Gleiss et al. 2013) may be due to the fact that in our present sample mainly children and adolescents of the lower social strata of Vienna have been included. Furthermore, childhood obesity is more frequently observable among groups of low socioeconomic status (Rogers et al. 2015; Spinosa et al. 2019), urban environments are in general obesogenic ones (Kirchengast and Hagmann 2021). Furthermore, the amount of more than 50 % children and adolescents with a background of migration complicates the situation. The problems of the usage of national height and weight references among populations with a high number of immigrants were already discussed by Kirchengast and Schober more than ten years ago (Kirchengast and Schober 2009). Furthermore, the proportion of overweight and obese participants is quite high in the present sample. About 20 % of the boys and girls were classified as overweight or obese at the age of 6 years. At the age of 10 years about 30 % of the participants were overweight or obese. This was still true of about 25 % of the male and female adolescents at the age of 15 years. These high rates of overweight and obesity can be interpreted as a result of the low socioeconomic status of the present sample as well as of the high number of participants with a background of migration. The association between being overweight or obese and low socioeconomic status and a background of migration is well described in a huge number of studies (Ruedl et al. 2019; Vilar-Compte et al. 2021; Moreira and Gonçalves 2020; Riedl et al. 2019; Eiholzer et al. 2021).

The hypothesis tested in the present study could be partially verified Body height at the age of 6 years and 10 years was significantly positively associated with the BMI at the age of 6 or 10 years. This was true of both sexes. Girls as well as boys who were classified as tall or extremely tall at the age of 6 years, or at the age of 10 years showed a significantly higher BMI at the age of 6 years and also at the age of 10 and 15 years, while in contrast children classified as short at the age of 6 and/or 10 years always showed the significantly lowest BMI values. This was again true of both sexes. These results correspond to the observations of the positive impact of higher weight status on linear growth (Komlos 1993; Steckel 1995). Body height at the age of 15 years, however, was not significantly associated with the BMI at the age of 6, 10, or even 15 years among girls. Among male participants, body height at the age of 15 years was significantly associated with BMI at the age of 10 years. These results obtained by Duncan's analyses were corroborated by the results of the regression analyses focusing on association patterns between the body height and the BMI, sex, migrant status, and the socioenvironmental factor.

At the age of 6 years, body height was significantly associated with sex, migrant status, and socioenvironmental factors describing the residential area of the child. This result confirms the high impact of socioenvironmental factors besides biological factors such as sex and BMI on the growth process. The results are in accordance with the SEPE concept (Bogin 2021b) because a significant association between body height and sociocultural and socioenvironmental factors could be stated. At the age of 10 years, body height was significantly positively associated with the BMI at the age of 6 and 10 years and the migrant status only. Sex and the socioenvironmental factors were not significantly related to body height at this age. At the age of 15, however, no significant association between BMI and body height could be proved. Body height was only significantly associated with sex and BMI at the age of 10 years. in summary, a higher BMI at the age of 6 and 10 years was independently associated with increased body height during the prepubertal phase. These results are in accordance with those of several previous studies (He and Karlberg 2001; Kain et al. 2005; Buchan et al. 2007; Navti et al. 2015). After puberty, however, no significant association between body height and BMI could be proved. Furthermore, no significant association with sociocultural or socioenvironmental factors could be stated. Therefore, the hypothesis tested in the present study was partly falsified. These findings corresponded nevertheless to the results of previous studies (van Dommelen et al. 2014; Holmgren et al. 2017).

Several explanations for the association patterns between body height and weight status have been presented. Before discussing the individual interpretations and explanations of the association between body height and weight status, it is important to note, that linear growth and consequently body height, but also weight gain, weight status, and finally obesity were multifactorial caused conditions (Kumanyika 2008; Bogin 2021a).

From a physiological viewpoint, somatic growth is also mediated by hormonal factors (Shalitin and Gat-Yablonski 2022). Growth hormone (GH) plays an essential role in subadult life. It stimulates, together with sex hormones, in particular androgens, and thyroid hormones, linear growth (Benyi and Sävendahl 2017). Interestingly, GH, which acts mainly through IGF-1, has also lipolytic effects. Consequently, the GH should increase linear growth, on the other hand, it should reduce fatness. However, even obese children often experience accelerated linear growth, although they showed reduced GH levels, a decreased frequency, and decreased amplitude of GH secretion (Kreitschmann-Andermahr et al. 2010). It is suggested that, increased numbers of GH receptors in peripheral tissue and increased levels of Growth Hormone binding globulin among obese children may result in accelerated growth among overweight and obese children (Kratzsch et al. 1997; Bouhours-Nouet et al. 2007).

Besides this physiological regulation we have to consider environmental and social factors. At the age of 6 years, the sociocultural environment and the background of migration are independently positively associated with body height, but with increasing age, these sociocultural factors decrease in their importance. At the age of 10 years, only the background of migration is still associated with the body height, besides the BMI at the ages of 6 and 10 years. At the age of 15 only sex and the BMI at the age of 10 years are associated with body height.

The significantly positive association between body height and BMI during the prepubertal phase maybe explained by the effects of developmental tempo. As pointed out in the introduction section, growth is a dynamic process that is a matter of size but also of tempo (Hermanussen 2010; Mumm et al. 2014). Growth, which is defined as an increase in size (amplitude) over time (Hermanussen 2011; Hermanussen and Scheffler 2022), is highly related to developmental tempo, which differs according to genetic as well as environmental factors during childhood. Therefore, we have to distinguish between slow- and fast-maturing children, which differ at the same calendar age not only in their status of maturation but also in growth and therefore in body height (Hermanussen 2011). A higher weight status during childhood enhances developmental tempo, pubertal maturation and somatic growth, resulting in earlier sexual maturation and greater body heights. The body height-BMI associations demonstrated in the present study may be due to differences in developmental tempo. Unfortunately, we have no information regarding the parameters of sexual maturation such as age at menarche. Nevertheless, we can assume that higher weight status may enhance developmental tempo and, in this way, somatic growth and results in increased body height. One important parameter affecting developmental tempo is energy supply, often expressed in weight status. Higher weight status is commonly associated with a higher amount of adipose tissue, which may be interpreted as energy storage., A higher amount of adipose tissue enhances development such as skeletal and reproductive maturation. Especially among girls a higher amount of body fat is associated with accelerated linear growth and increased skeletal as well as sexual maturation (Chung 2017). Consequently, before puberty, the association between weight status and body height is a positive one, because a better energetic situation enhances developmental tempo, and in this way, linear growth. After sexual maturation, higher estrogen levels induce the closure of the epiphyseal plate (Grumbach 2000). Consequently, linear growth is completed earlier and no further positive association between body height and weight status can be observed after sexual maturation. The results of the present study corroborate this point of view and are consistent with the results of He and Karlberg (He and Karlberg 2001), who reported a positive association between body weight or overnutrition on body height during childhood, but who found no beneficial effect of higher body weight during childhood on the body height during adolescence, because the temporary increase in height gain in childhood was compensated by an earlier pubertal maturity and a subnormal height gain in adolescence (He and Karlberg 2001). These effects are mainly observed among girls, a high weight status however is associated with a higher amount of adipose tissue among boys, too. A higher amount of adipose tissue may enhance estrogen synthesis in adipocytes via the aromatization of androgens to estrogens (Nelson and Bulun 2001). Consequently, among overweight and obese boys, linear growth may be reduced at the time of pubertal transition resulting in no further significantly positive associations between body height and weight status during early adolescence. These effects may be used as explanations for the body height–weight status association patterns described in the present study.

Limitations

The present study has some limitations which have to be mentioned. We had no sufficient information regarding sexual maturation of our participants. Therefore, we can only assume that a higher weight status is associated with increased developmental tempo. Furthermore, no information regarding socioeconomic parameters such as family income was available. We could only reconstruct the socioenvironmental factors of the residential area of the participants. Therefore, important cofactors could not be considered. The strength of the study is the quite high number of participants and the longitudinal design.

Conclusion

Linear growth and weight status are associated during the childhood and juvenile phase of life. Taller children show higher weight status and a higher prevalence of obesity than their shorter peers at the age of 6 and 10 years. The "fattest" during childhood is also the tallest at this phase of life. During early adolescence, however, a high weight status does not further enhance linear growth. At the age of 15, the main factor influencing body height was sex. Furthermore, the association patterns differed between males and females at the age of 15. Among female participants, the extremely tall individuals showed the lowest BMI, while among male participants, the lowest BMI was found among the shortest individuals. The highest BMI at the age of 15 was exhibited by the extremely tall males.

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